Testing Lunar Return Thermal Protection Systems Using Sub-Scale Flight Test Vehicles

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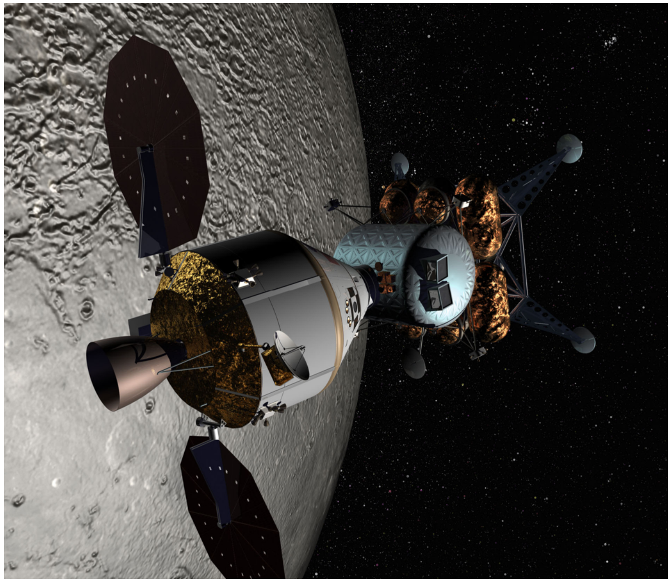
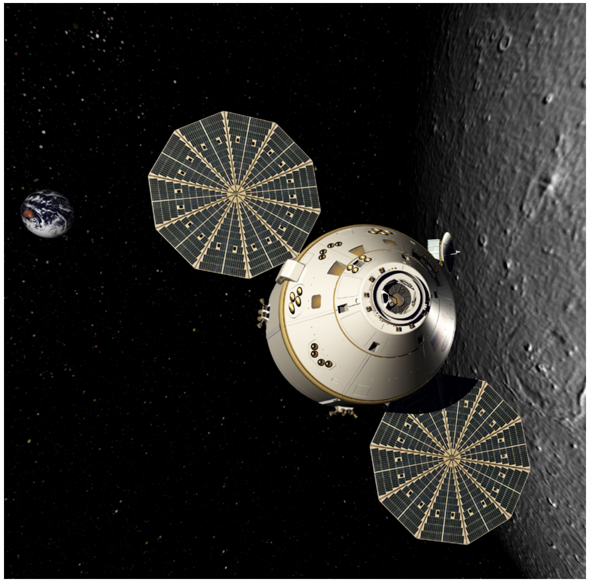
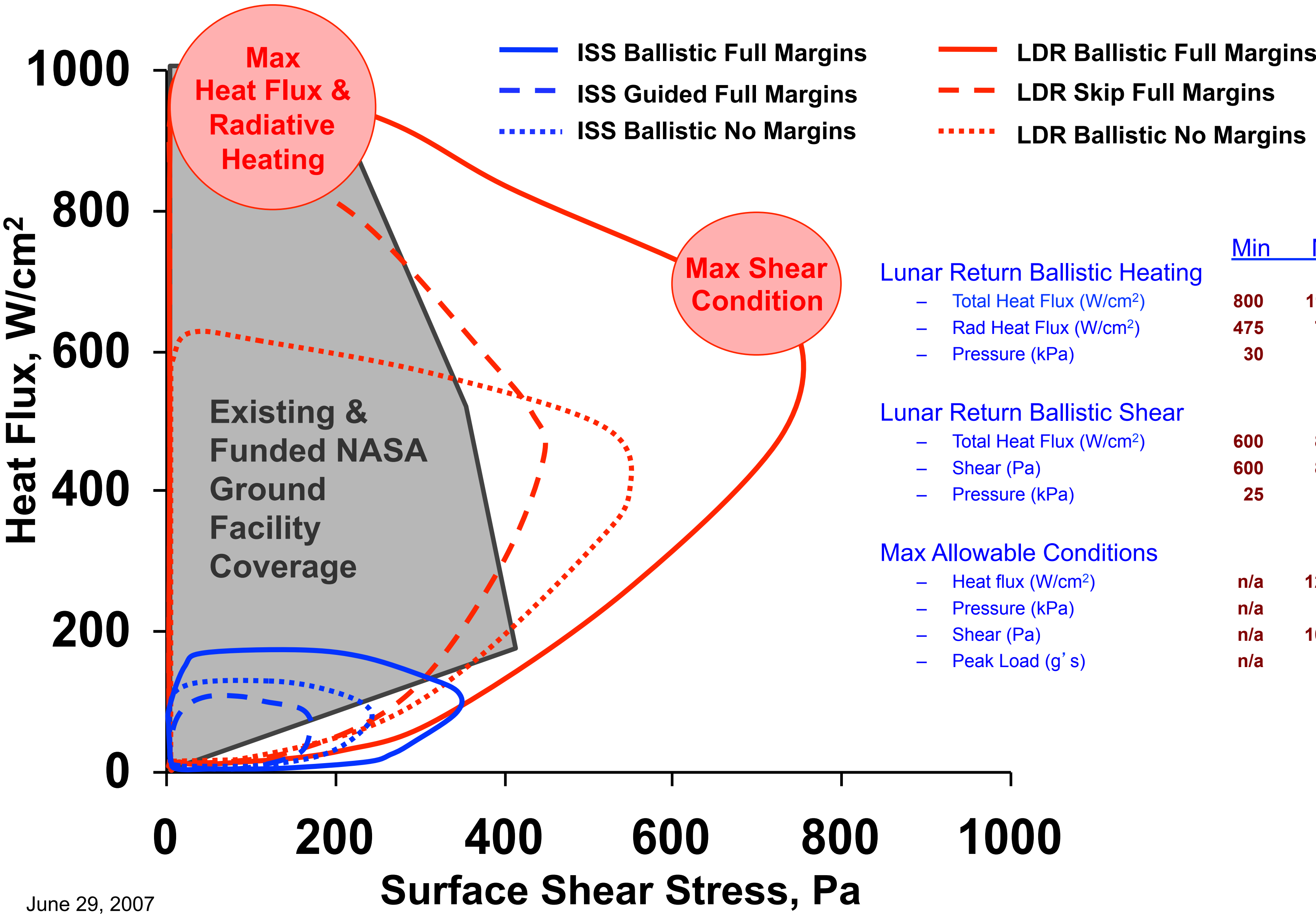
Rationale & Overview

- A primary objective of NASA's Vision for Space Exploration (VSE) is to revisit the lunar surface by ~ 2018. The centerpiece of VSE is the Orion Crew Exploration Vehicle (CEV).
- Prior to returning humans back from the moon, two key Orion technologies must be tested to ensure safe return.
  - Segmented Phenolic Impregnated Carbon Ablator (PICA) heatshield with gaps and seams.
  - Skip entry guidance to allow landing at a continental U.S. (CONUS) landing site.
- **TORCH Study Motivation: Is there a less expensive way to flight test these technologies without a full-scale Orion lunar flight?**

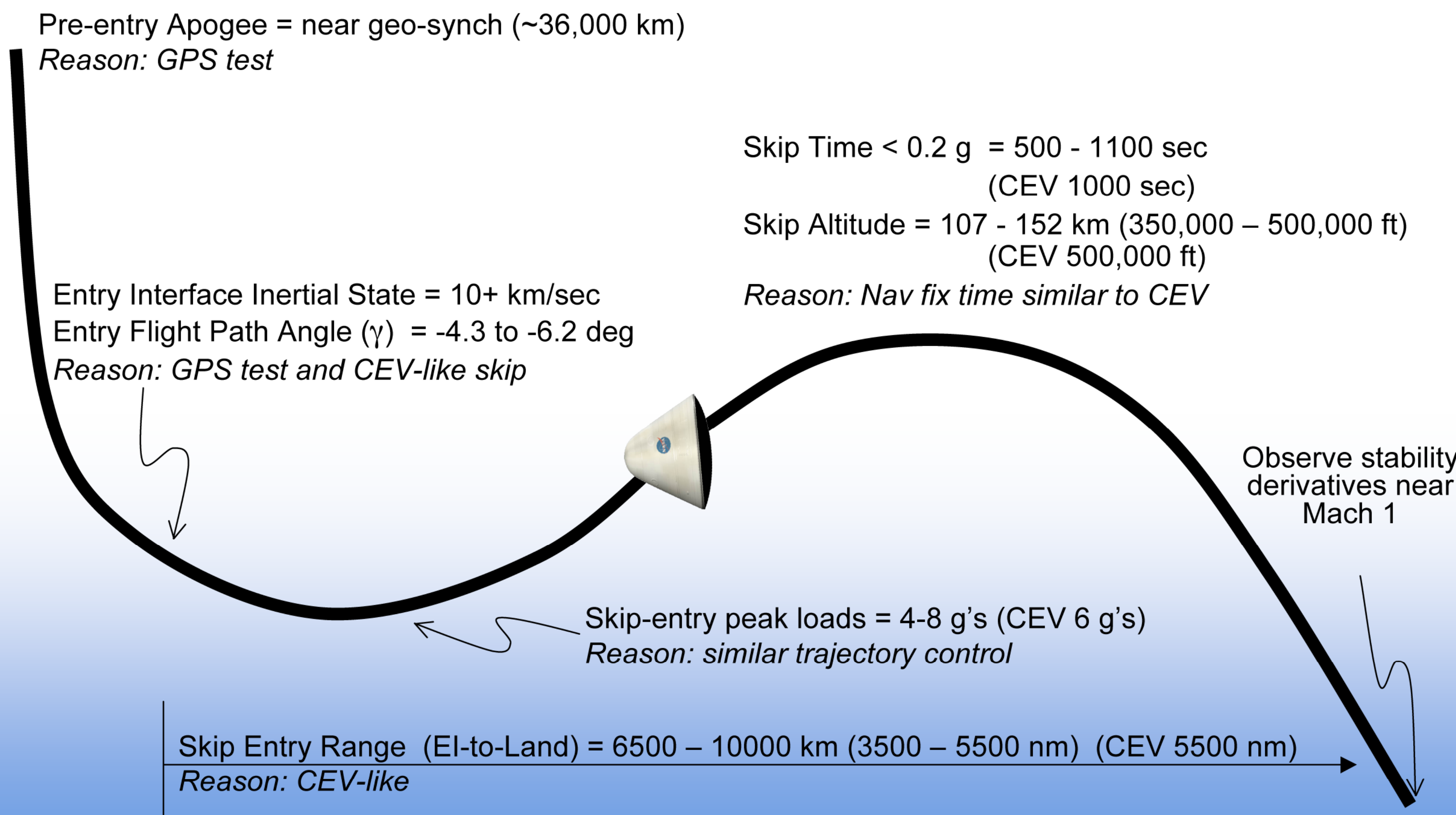




Required Flight Test Conditions



	Min	Max
Lunar Return Ballistic Heating		
– Total Heat Flux (W/cm^2)	800	1100
– Rad Heat Flux (W/cm^2)	475	700
– Pressure (kPa)	30	60
Lunar Return Ballistic Shear		
– Total Heat Flux (W/cm^2)	600	800
– Shear (Pa)	600	800
– Pressure (kPa)	25	60
Max Allowable Conditions		
– Heat flux (W/cm^2)	n/a	1200
– Pressure (kPa)	n/a	90
– Shear (Pa)	n/a	1000
– Peak Load (g's)	n/a	30

Skip Entry Test Trajectory



Combining Efforts

TORCH
LEADING THE WAY FOR LUNAR RETURN
TESTING OF REENTRY CAPSULE HEATSHIELD

+

Yuma
Skip Entry Demonstrator

=

LE-X
Lunar re-Entry Experiment

Balancing Project Costs & Risks

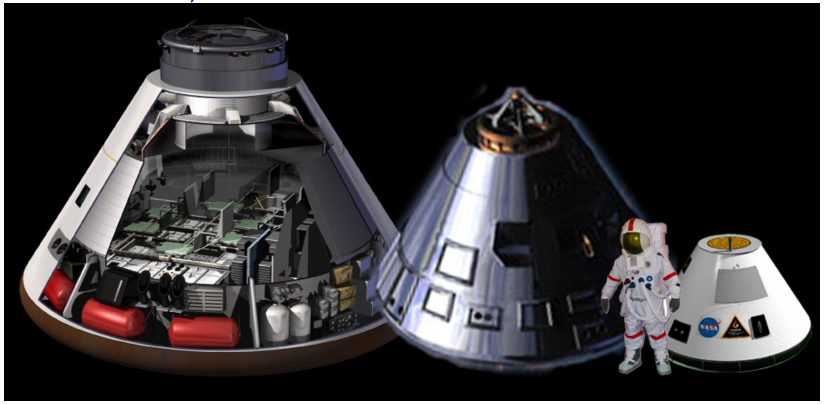
- The LE-X flight test study focused using small, lightweight, & simple test vehicles and reusing this design for multiple flights.
  - The mission design team attempted to minimize the number of vehicle types so that non-recurring costs are minimized. Different aerothermal conditions achieved by varying the ballast mass (thus the ballistic coefficient) and entry conditions.
  - Smaller, lighter entry vehicle ⇨ Smaller launch vehicles ⇨ Lower program costs
  - Maximize # of target aerothermal conditions achieved on each flight ⇨ Minimize # of flights and achieve more realistic test environments
  - Entry condition targeting provided by launch vehicle.
- Avoid multiple test vehicles on single launcher
  - Apply lessons learned to the next flights
  - Minimize # of "eggs in one basket"
- Flight test vehicles are single-string except for data acquisition system, which uses TDRSS, landing site receivers, & on-board non-volatile flash memory to capture flight telemetry. Additionally, the vehicle must be recovered for post-flight heatshield analysis.
- Geometrically scaled CEV allowed the use of the CEV Aerothermal database to find entry conditions and vehicle parameters that meet desired test conditions and leads to better traceability to the full scale vehicle.

LE-X Mission Design

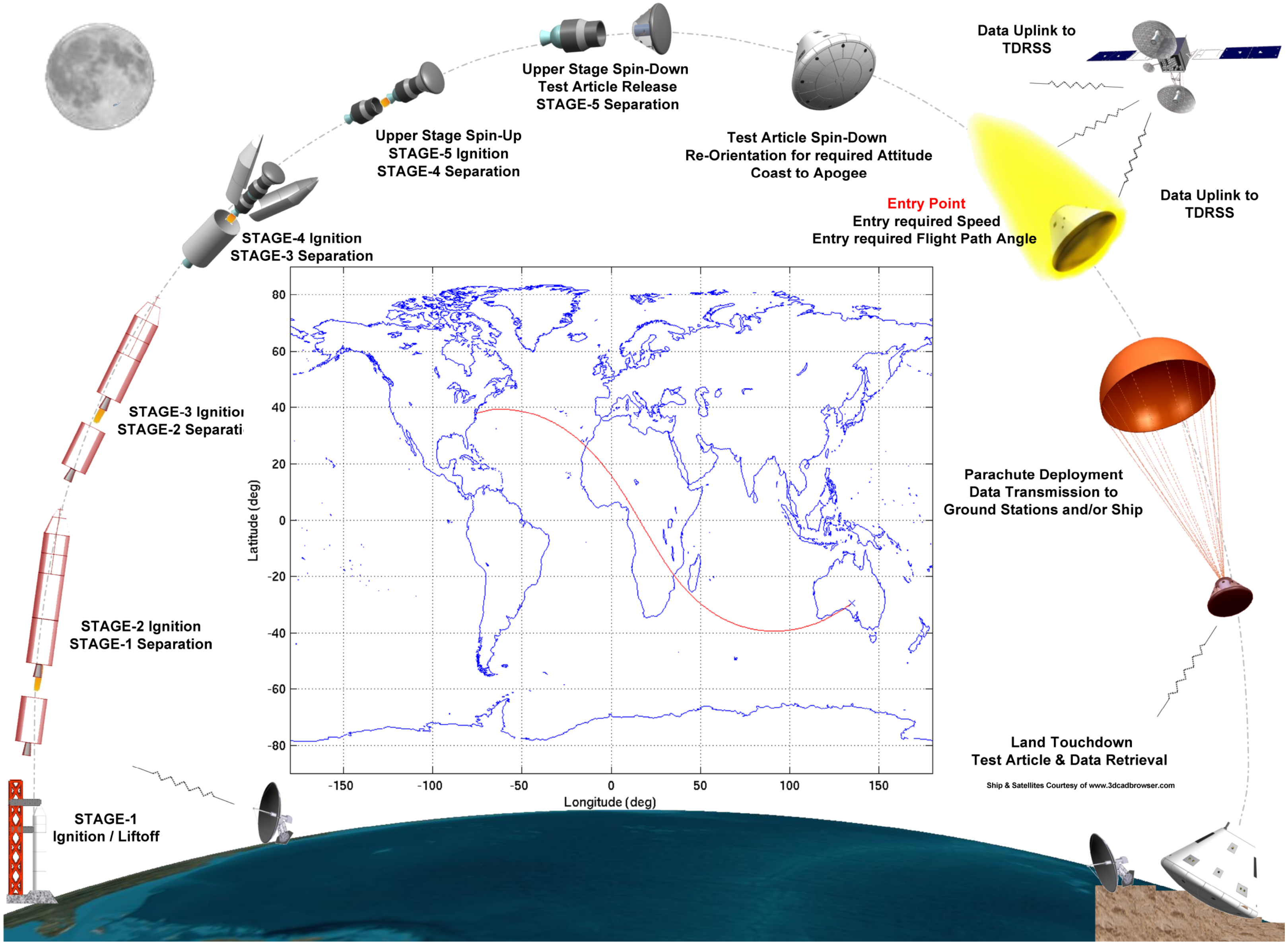
- **Primary Mission Design Objectives**
  - Collect data on thermal protection system (TPS) performance under lunar return ballistic heating and shear environment
  - Demonstrate skip demonstration guidance (late addition to TORCH project resulting in the combined LE-X project).
  - Minimize costs by minimizing vehicle entry mass and diameter, and the number of flights.
- **Trade Space Parameters:**
  - Vehicle entry mass: 200 kg to 1250 kg
  - Vehicle diameter: 0.5 to 2.2 m
  - Entry velocity
  - Entry flight path angle (EFPA or γ)

See the TORCH Mission Design Poster Session for additional details.

- **Key Findings:**
  - The Orion aerothermal test requirements cannot be met with vehicle diameters < 2m
  - All combination of objectives on a single flight are possible EXCEPT for shear combined with skip (**results in a minimum of TWO flight tests**)
    - Skip is NOT compatible with shear due to the shear test altitude being too low for a skip trajectory (vehicle does not have enough lift to pull out of the atmosphere after achieving shear conditions)
- **PROPOSED FLIGHT TESTS:**
  - **Flight Test 1: Ballistic flight test for radiation & shear (850 kg)**
  - **Flight Test 2: Skip flight test (1250 kg)**
  - Common vehicle design design.
    - 2 meter diameter
    - Ballistic number adjusted by varying the ballast



Typical LE-X Mission



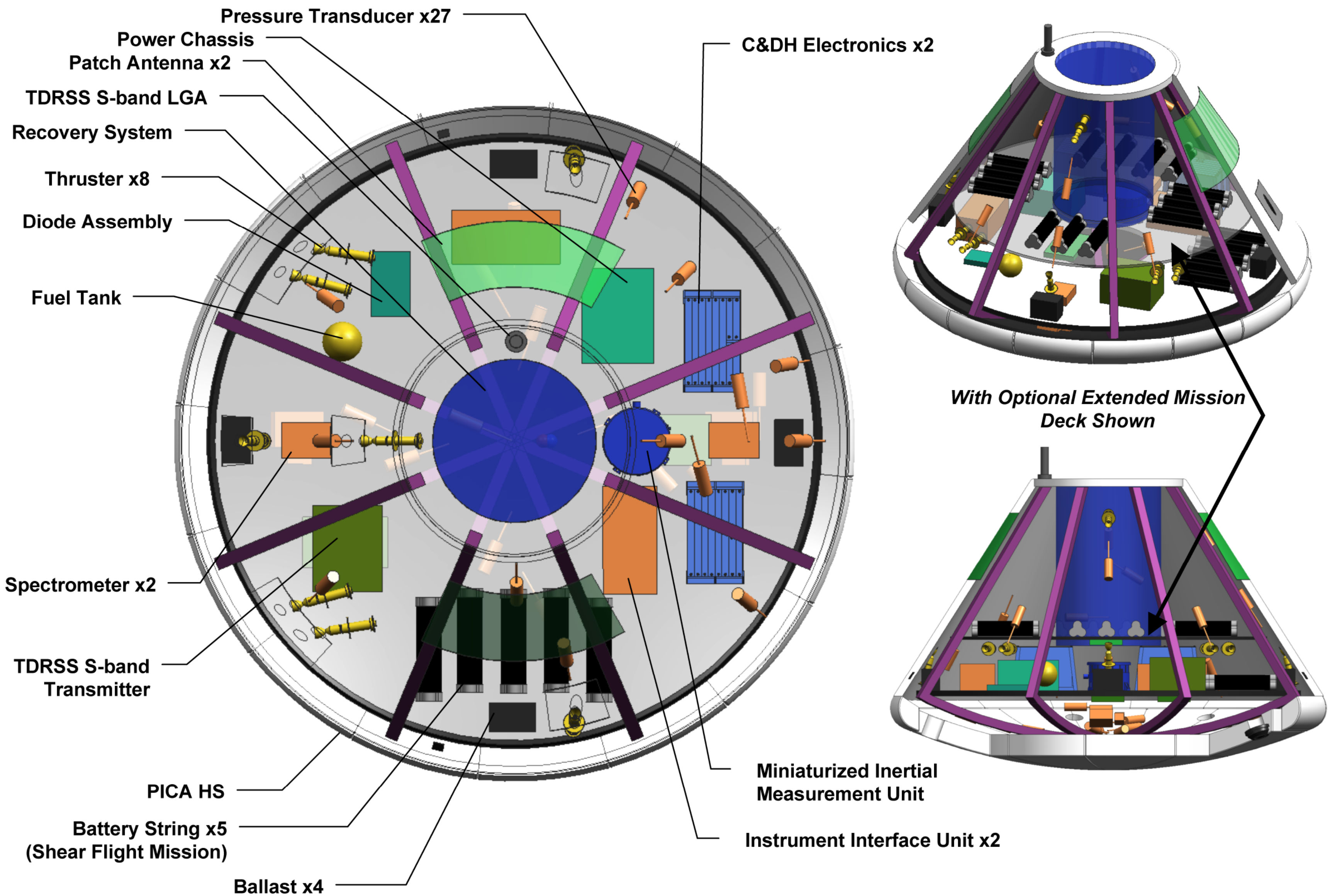
Launch Vehicle Options

- **Launch vehicle survey determined there are viable launch vehicles from both United Launch Alliance (formerly Boeing), LMA, and SpaceX.**
  - Orbital Sciences (OSC) vehicles are not viable for CEV test requirements and 2 m capsule
  - Missions using Delta IVs are almost certainly possible; further assessment is required
- **The Constellation Program Office has directed the LE-X team to keep all launch vehicle options open.**

	Vehicle Entry Mass Capability by Mission		
Launch Vehicle	**Ballistic Mission** **12.1 km/s (39.7 kft/s) Entry** **850 kg (1874 lb) Req'd**	**Skip Mission** **10.5 km/sec (34.4 kft/s) Entry** **1250 kg (2756 lb) Req'd**	**Launch Vehicle Cost**
OSC Minotaur IV	No Solution	No Solution	\$20M-\$22M
SpaceX Falcon 9	1300 kg (2870 lb)	2550 kg (5620 lb)	\$35M*
OSC Minotaur V	No Solution	No Solution	\$38M (1st flight) \$29M (subseq.)
Boeing Delta II 7925H	No Solution	>1250 kg (>2760 lb)	\$90M* RLEP \$125M otherwise
LMA Atlas V 431	>850 kg (>1870 lb)	>1250 kg (>2760 lb)	\$125M
Ares I	>> 850 kg Req's 1st/2nd stages ballast **	>1250 kg*** (>2760 lb)	?

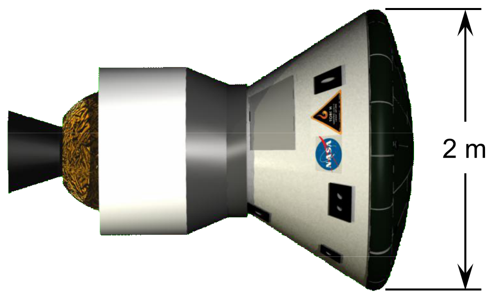
*Possibility that costs have already been covered by Agency.
**Reducing ballast on 1st/2nd stages will increase peak dynamic pressure beyond that on CEV launch
***With ballast added on 1st/2nd stages to maintain peak dynamic pressure equal to CEV launch

Flight System Highlights



See the TORCH Flight System Poster for additional details.

Recommended Flight Test Program



Atlas V / Falcon 9 Class

Delta II / Falcon 9 Class

	LE-X-1 Ballistic	LE-X-2 Skip	Program Total
Entry Vehicle Diameter (m)	2	2	
Entry Vehicle Mass (kg)	850	1200	
Inertial Entry Velocity (km/sec)	12.1	11.0	
Inertial Entry Flight Path Angle (deg)	-6.7	-6.3	
Flight Vehicle (2 with long lead parts for 3rd), Instrumentation, & Operations Cost (w/o reserves)	$94M	$33M	$127M
Flight Cost excluding Launch Vehicle (w/ 30% reserves applied to both vehicles)*	$122M (incl. 1st flight dev. costs)	$43M (recurring cost of 2nd flight test vehicle only)	$165M
	or 91M €	or 32M €	or 123M €

* **Flight Vehicle Costs:**

- Costs in FY2007 dollars without inflation.
- Assumes two identical and concurrent flight builds. Extended mission deck integrated into the LE-X-2 (skip mission) vehicle.

- **Launch vehicle costs for two launches are expected to range between $70M and $250M.**

Conclusions

- Subscale test vehicles can be versatile and cost effective platforms for TPS and skip entry guidance testing.
  – A two-flight test program can qualify the lunar return heatshield and test the skip entry guidance.
  – The LE-X program will cost significantly less than a lunar test flight of a full Orion vehicle.
- The LE-X infrastructure can be inexpensively leveraged for future flight test objectives.
  – Fundamental aeronautics research into high-speed flows to provide data to develop and validate simulation tools
  – Testing of future TPS materials such as for Mars return (~14 km/s).
  – Aerocapture
- First flight date under discussion: 2011 - 2014
- International collaboration? Let's talk!
  – Challenge may be the flight schedule. The first LE-X must fly by 2014 to maximize benefits to the Orion CEV development. Future flights?